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The distance of the Fornax Cluster based on Globular Cluster Luminosity Functions

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Abstract. We present Globular Cluster Luminosity Functions for four ellipticals and one S0-Galaxy in the Fornax cluster of galaxies, derived from CCD photometry in V and I. The averaged turnover magnitudes are $V_{TO} = 23.80 \pm 0.06$ mag and $I_{TO} = 22.39 \pm 0.05$ mag, respectively. We derive a relative distance modulus $(m-M)_{Fornax} - (m-M)_{M87} = 0.08 \pm 0.09$ mag using the turnover of M87 based on HST data.

Key words: *(Galaxy:)* globular clusters: general ; **Galaxies: clusters: individual: Fornax** ; Galaxies: elliptical and lenticular, cD ; **Galaxies: individual: NGC 1399, NGC 1374, NGC 1379, NGC 1387, NGC 1427**

1. Introduction

There is a tremendously rich literature on the distance determination of the Virgo cluster (e.g. de Vaucouleur 1993). Relatively little has been worked on the Fornax cluster of galaxies, although it offers several advantages with respect to the Virgo cluster: it is more compact, does not show substructure, and is a spiral-poor, evolved galaxy cluster, where one can suspect that the elliptical galaxies projected near the center are indeed spatially concentrated.

In this Letter, we apply the method of globular cluster luminosity functions (GCLFs) to derive the distances of four ellipticals in the Fornax cluster. The central point of this method, namely the universality of the turnover (TO) magnitude is still a subject of some debate (e.g. Harris in Jacoby et al. 1993 , Sandage & Tammann 1995, Richtler 1995). We show that among our target galaxies, the turnover magnitude scatters with a dispersion of 0.23 mag in V and only 0.14 mag in I, which indeed is evidence for a universal turnover.

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2. Data, reduction, photometric calibration

The full presentation of the data, together with a general presentation of the globular cluster system (GCS) will be given in a forthcoming paper, so here we restrict ourselves to some basic remarks.

Our targets were the galaxies NGC 1399, 1374, 1379, 1387, 1427 (Table 1). The observations have been performed with the 2.5m DuPont telescope at Las Campanas Observatory, Chile, in the period Sept. 26-29, 1994. The CCD was a Tektronix chip with a pixel size of 0.227 $''$, resulting in a frame with dimension $7.4' \times 7.4'$. Deep exposures have been gained in Johnson V and Cousins I. Only NGC 1399 was covered by four overlapping frames, the other targets are much less extended and fit each on one frame. The seeing conditions were of medium quality, ranging from $1.0''$to $1.5''$. The limiting magnitude was approximately V=24 mag.

Modelling and subtraction of the target galaxies has been done with IRAF routines, finding and photometry of point sources with DAOPHOT II under IRAF. The differences between PSF and aperture photometry could be determined with an accuracy of better than 0.015 mag. The photometric calibration has also been done with IRAF routines, using standard stars from Landolt (1992). About 30 standard star measurements were made nightly under photometric conditions. The mean residual of calibrated magnitude to standard star magnitude is about 0.02 mag for each night.

3. Extraction of the luminosity functions: Treatment of background and completeness

Obviously, a proper knowledge of the background population is essential for deriving a GCLF, since we cannot distinguish between point-like background sources and globular clusters. With the exception of NGC 1399, the GCSs of the galaxies are considerably smaller in extent than the framesize so that the background could be determined lo-

Table 1. The observations of the Fornax galaxies obtained with the 2.5m telescope on Las Campanas

galaxy	Filter	Obs. date	exposure	FWHM
NGC 1374	V	28 9 94	2×1200s	1.″2
	I	29 9 94	1200s, 2×600s	1.″5
NGC 1379	V	29 9 94	2×1200s	1.″2
	I	26 9 94	3×1200s	1.″4
NGC 1387	V	28 9 94	2×900s	1.″3
	I	28 9 94	2×900s	1.″2
NGC 1427	V	26 9 94	3×1200s	1.″5
	I	26 9 94	3×1200s	1.″3
NGC 1399	I	27/28 9 94	4×900s	1.″2
	V	27/28 9 94	4×900s	1.″0

Table 2. Turnover values of the Fornax GCLFs fitted by gaussians and t_5 functions.

galaxy	V_0^{Gauss}	I_0^{Gauss}
NGC 1374	23.52 ± 0.14	22.60 ± 0.13
NGC 1379	23.68 ± 0.28	22.54 ± 0.34
NGC 1427	23.78 ± 0.21	22.31 ± 0.14
NGC 1399	23.90 ± 0.08	22.36 ± 0.06
galaxy	V_0^{t5}	I_0^{t5}
NGC 1374	23.44 ± 0.13	22.49 ± 0.12
NGC 1379	23.65 ± 0.26	22.77 ± 0.44
NGC 1427	23.63 ± 0.19	22.22 ± 0.13
NGC 1399	23.90 ± 0.08	22.27 ± 0.05

cally. A coarse selection of GC candidates with respect to extended objects was done by selecting sources with PSF profiles. The remaining background population consists mostly of distant galaxies, to some extend also of foreground stars. Leaving details for a forthcoming full data presentation, we show in Fig. 1 for V the relative contribution of the total counts, the background, and the subtracted counts in dependence on magnitude. The dashed line shows in addition the completeness, calculated by artificial star experiments.

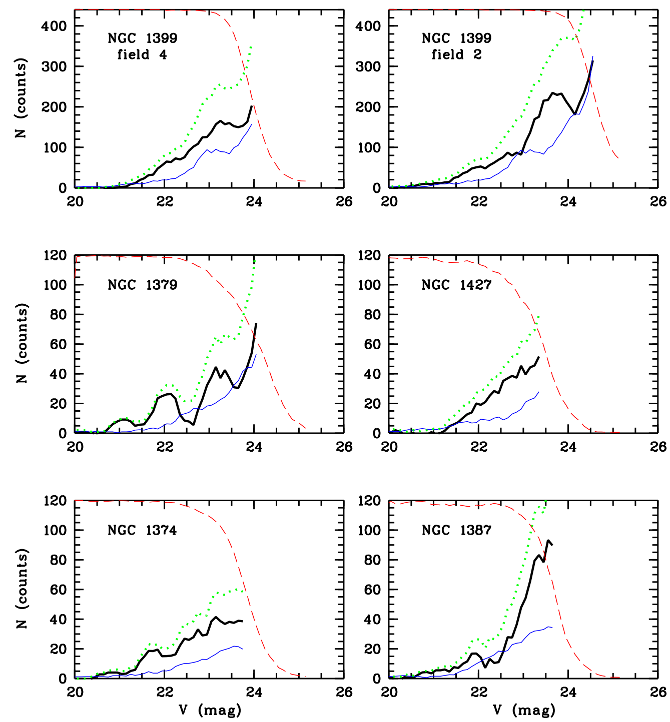

Fig. 1. This plot shows for our 5 target galaxies the completeness corrected total counts (thick), background counts (dotted), the background subtracted counts (thin), and the completeness (dashed), binned in 0.5 mag intervals in V. Obvious galaxies are already removed.

4. Luminosity Functions

During the last years, a lot of work has been done as for the correct representation of the GCLF (e.g. Secker et al. 1992). We cannot enter this discussion here, but give GCLFs for two different representations with reference to the Milky Way system (see next section): a Gaussian function with a fixed dispersion of 1.2 mag in V and and a t_5-function with a fixed dispersion of 1.1 mag. The counts have been binned in 0.5 mag bins. The dispersions were determined by fitting GCLFs with free parameters but it should be emphasized that the dispersion must be fixed when comparing the TO of the Fornax GCLFs.

Fig. 2 shows the results for the GCLFs in V and I, respectively. Table 2 summarises the results for different fits, done with Gaussians and t_5-functions. Because of its poor GCS no GCLF of the S0 galaxy NGC 1387 could be fitted. Taking averages for the turnover magnitudes, weighted with inverse square of the errors, we get for the mean turnover of the Fornax cluster 23.80 ± 0.06 in V, 22.39 ± 0.05 in I for gaussians and 23.73 ± 0.07 in V, 22.30 ± 0.04 in I for t_5. The given uncertainties represent the errors of the mean.

5. The zero-point from the galactic globular cluster system

The zero-point of the distance determination via GCLFs is given by the galactic GCS. The uncertainty concerning distances to galactic globular clusters still determines the absolute uncertainty inherent to this method of deriving the distance of the Fornax cluster. For the absolute turnover magnitude of the Milky Way system, one can find values as different as 0.4 mag in the literature (e.g. Secker 1992, Sandage & Tamman 1995), related to the adopted dependence of the brightness of horizontal branch stars on metallicity (see equations below). This uncertainty will probably be overcome, once it is possible to derive GC distances from nearby subdwarfs. At present, one has to accept it and we give the turnover magnitudes

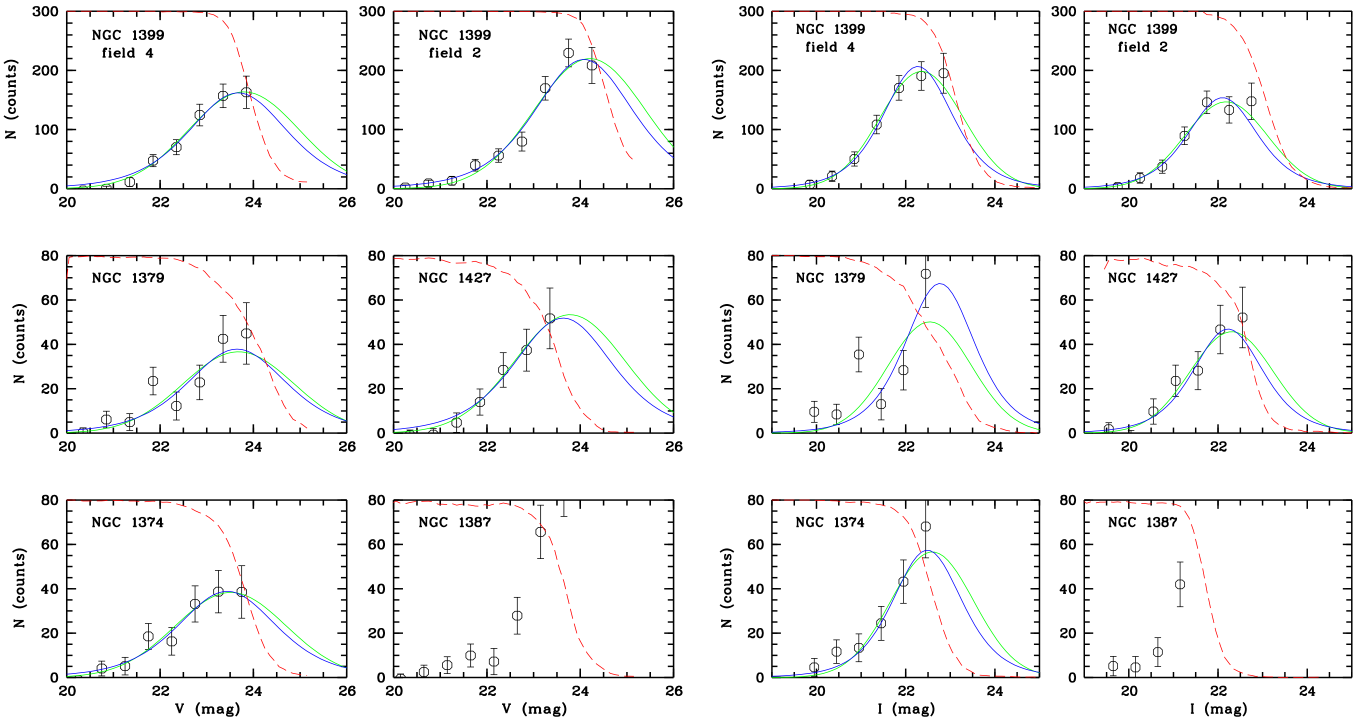

Fig. 2. Globular Cluster Luminosity Functions for the five Fornax galaxies in V an I. The GCLFs are corrected for completeness and background contamination. Overplotted are fitted gaussians (thick lines) and t_5-functions (thin lines). The dashed line shows the completeness function calculated by artificial star experiments. NGC 1387 has a too sparse GCS in order to fit a LF.

for two different relationships regarding the metallicities of horizontal branch stars according to Sandage & Tammann (1995) and Harris et al. (1991) (note that Carney et al. 1992 derive $M_V(HB) = 0.16 \cdot [Fe/H] + 1.02$) :

$$M_V(HB) = 0.30 \cdot [Fe/H] + 0.94 \text{ (S\&T)} \quad (1)$$

$$M_V(HB) = 0.20 \cdot [Fe/H] + 1.0 \quad \text{(Harris)} \quad (2)$$

For deriving the Milky Way GCLF in the same way as the Fornax data, we used the compilation of Harris (1994) which contains the V magnitudes of all 142 known clusters. The I magnitudes were calculated using the integrated color indices and a reddening correction (Dean et al. 1978):

$$M_{I,0} = M_{V,0} - ((V - I) - 1.35 \cdot E_{B-V}) \quad (3)$$

We made no restrictions concerning galactocentric distance and reddening. We fitted the GCLFs in V and in I after binning in 0.5 mag. The dispersion $\sigma_V = 1.2$ mag and $\sigma_I = 1.1$ mag (for Gaussians) were determined by a free fit. Since the turnover magnitudes are practically independent of whether a Gaussian or a t5-function is fitted, Table 3 only contains the results of the Gaussian representation (this is of course not the case, if only the ascendent branch of the GCLF or part of it is visible).

Corresponding to Table 3, the distance moduli to the Fornax cluster in V are 31.20 ± 0.13 and 30.89 ± 0.13 in I,

Table 3. The absolute turnover magnitudes in V and I for the galactic GCLF. Different relations for the metallicity dependence of the brightness of horizontal branch stars of Sandage & Tammann (1995) and Harris et al. (1991) were used. The data have been binned in 0.5 mag bins.

V_0 $\sigma = 1.2$ mag	I_0 $\sigma = 1.1$ mag	calibration of RR-Lyrae stars
-7.40 ±0.12	-8.53 ±0.10	Harris et al. (1991)
-7.68 ±0.12	-8.73 ±0.10	Sandage & Tammann (1995)

using the RR-Lyrae scale of Harris et al. (1991). Following Burstein & Heiles (1984) we adopted zero absorption. In the next section, we argue that the smaller modulus in I may be understood as a metallicity effect.

6. Metallicity corrections

To what degree is the turnover of GCLFs universal? In particular, do the GCSs of spiral and elliptical galaxies have the same turnover? It is a remarkable fact that the *mass functions* of globular clusters in galaxies which are so different in their properties as the Milky Way and M87, exhibit the same mass function slope, which may be regarded as the underlying property for a universal turnover (Harris & Pudritz 1994 , McLaughlin & Pudritz 1995). If

this is so, then one should expect a metallicity dependence in the turnover since at a given mass, metal-poor globular clusters are brighter than metal-rich clusters. This behaviour has been studied by Ashman et al. (1995) assuming a universal globular cluster mass function and using the (M/L)-[Fe/H] relationships given by Worthey (1994) .

In this sense, we also expect the GCS of spirals to be more metal-poor than those of ellipticals, because the metal-rich bulges and their associated GC populations are dominating, while in spirals like the Milky Way, the GC population of the bulge comprises only a handful of clusters (e.g. Richtler 1995). If this is the case then we overestimate the distance modulus of a metal-rich GCS by calibrating it through the galactic system. The larger distance modulus in V may be understood in this way. To correct for it, we had to know the difference in the mean metallicity between the galactic system and the Fornax GCSs. Unfortunately, we only have the integral (V-I)-colour, which is no sensitive metallicity indicator. Adopting zero reddening towards the Fornax cluster and using the colour-metallicity relation of Couture (1990)

$$(V-I)_0 \;=\; 0.2[Fe/H] + 1.2 \qquad (4)$$

we calculated the shifts in the turnover on the basis of Ashman et al. (1995) with respect to the Milky Way for each galaxy (see Table 4). On average we get a mean Fornax turnover $< V_{TO} >= 23.67 \pm 0.06$ in V and $< I_{TO} >= 23.32 \pm 0.05$ in I. The resulting distance moduli are 31.07 ± 0.13 in V and 30.85 ± 0.11 in I (using the RR-Lyrae scale of Harris et al. 1991).

7. The relative distance to Virgo

The direct comparison of the turnover of GCLFs of elliptical galaxies only avoids all the uncertainties in the predicted influence of metallicity and the difficulties in its determination. A comparison of the turnover of galaxies in the Fornax and the Virgo cluster therefore should yield an accurate relative distance. The GCLF of M87 recently has been observed with the Hubble Space Telescope (Whitmore et al. 1995 , Elson & Santiago 1995). The deep photometry of Whitmore et al. reached more than two magnitudes beyond the turnover of $V_{TO}^{M87} = 23.72 \pm 0.06$ mag. A galactic extinction of $A_V = 0.067 \pm 0.04$ mag towards M87 has been adopted. Because of its position in the core of the Virgo cluster, M87 provides a good reference for the relative distance modulus. Using the mean Fornax turnover of section 4, we derive

$$(m-M)_{Fornax} - (m-M)_{M87} = 0.08 \pm 0.09 \text{ mag} \qquad (5)$$

in good agreement with the recent determination $(m-M)_{Fornax} - (m-M)_{Virgo} = -0.06 \pm 0.15$ mag of Bureau et al. (1996) using the I-band Tully-Fisher relation. *Basically there is no difference in the distance of the Fornax cluster and of the Virgo cluster.*

Table 4. Colours, predicted shifts and corrected turnover of the GCLFs according to Ashman et al. (1995). The metallicities were computed using equation (4).

galaxy	V-I	[Fe/H]	ΔV	ΔI	V_0^*	I_0^*
NGC 1374	1.08	-0.64	0.21	0.09	23.31	22.51
NGC 1379	1.17	-0.19	0.40	0.15	23.28	22.39
NGC 1427	1.02	-0.94	0.10	0.05	23.73	22.26
NGC 1399	1.01	-1.39	0.09	0.04	23.81	22.29

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